THE LOCATION AND CORRELATION OF A SEQUENCE OF LAVA FLOWS FROM THE COLUMBIA RIVER BASALTS

SENIOR THESIS

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Requirements for the Degree of Bachelor of Science

by

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I wish to express my utmost appreciation to Dr. David Elliot for his patience and help in the writing of this paper. Thanks also go out to Dr. Ernest Ehlers for help in photography and petrographic descriptions. Special thanks also extended to Carol Eaton for typing this paper.

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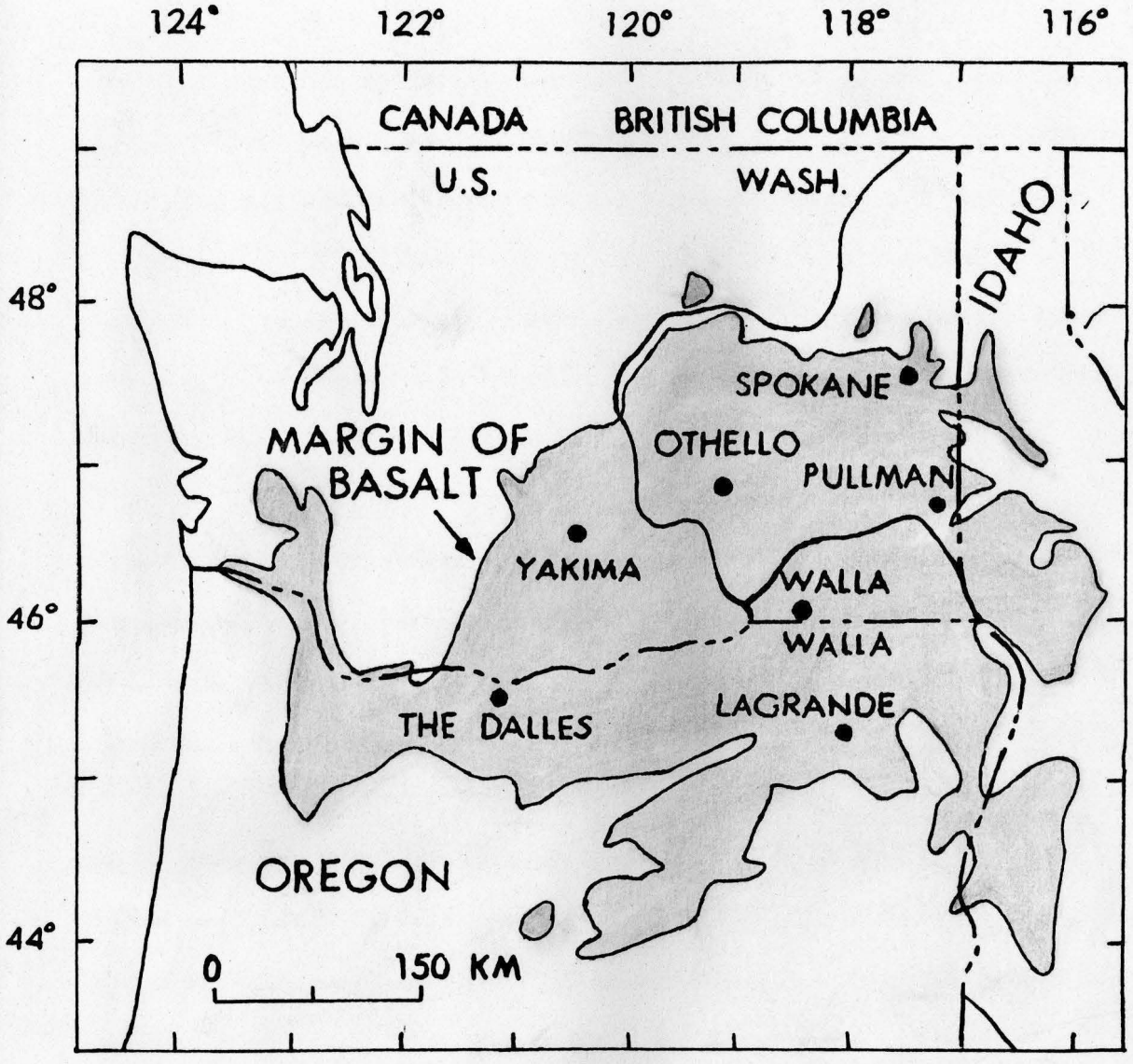

FIG 1

Inferred original distribution of Columbia River Basalt Group

After Swanson and others (1979)

INTRODUCTION

The great part of the Pacific Northwest is covered by rocks comprising the Columbia River Basalt Group. According to Hooper (1982), all rocks of this group are Miocene in age and were erupted during the time span covering about 17 million to 6 million years BP. During the first 3.5 million years of volcanic activity, over 95 percent of the flood basalts were extruded, covering an area of some 200,000 square kilometers and averaging more than one kilometer in thickness.

These basalts represent one example of a group of continental basalt flows found sporadically over the surface of the Earth. Numerous examples are found near the edges of rifted continents, such as those found in west Africa and eastern South America, which were formerly joined.

The basalts found in the Columbia River area of the Pacific Northwest probably represent a time of near continental breakup in this area. Tension necessary for the formation of fissures through which magma flowed was probably provided by the large subduction zone found to the west near the Pacific border. Evidence that this subduction zone was active at or prior to the time of extrusion of the basalt is shown by the volcanoes that occupied the site of the present Cascades. These volcanoes are a direct result of that subduction process.

The same subduction zone which indirectly aided in the extrusion of the Columbia River Group may also have been responsible for the closing down of the rifting mechanism some six million years ago. While still not clearly understood, plate migration and changing angle of subduction in the area has occured in the past. This could interfere with the mechanisms of rifting and eventually eliminate the production and extrusion of new magma.

Oceanic crustal basalt tends to have a significantly higher magnesium/iron ratio than continental flood basalt. This major difference in chemical composition has been hypothesized as the result of crystal fractionation at depth in chambers near the base of the crust, removing large quantities of olivine and clinopyroxene (Hooper (1982)). The major difference between this explanation and the classical model of crystal fractionation is that these deep chambers are renewed by more primary liquid from below. This liquid tends to buffer the variation in magnesium/iron ratios.

Compositional variations between individual flows in the Columbia River Group occur due to several major factors. These factors include variation in mantle source material, different degrees of partial melting and crystal fractionation in deep magma chambers. The high volume of extruded magma and great fissure systems point out the unlikehood that these variations are due to fractionation in shallow chambers.

Regional tectonic activity provided an important factor in the distribution of the Columbia River Group. During volcanism, the area of accumulation of magma was flanked by two active ridges. To the west lay the rising Cascade Range, consisting of volcanic piles sitting on a regional upwarp. On the east flank, upwarping following emplacement of the Idaho batholith was also providing a surface of relatively high relief. A third tectonic activity at the time was tilting of the area between these two ridges from east to west. In addition to this tilting, the area was also being affected by east-west tension and north-south compression. This is shown by the north-south trending dike network and east-west anticlinal folds.

Source dikes for the lavas are generally found in the east and southeast portions of the plateau near the Idaho-Washington and Idaho-Oregon borders.

A small concentration of source vents are also found in the southern portion of the plateau near north-central Oregon. All fissures run north-northwest to south-southeast and vary in length up to 150 Km.

Most of the post basaltic geologic structure formed in the Columbia River Group is relatively recent, mostly Pliocene and Quaternary in age. Structures existing prior to extrusion of the basalt, such as the Blue Mountain anticline, are exposed in the area but are comparatively rare. Many of these structures were being formed around the time of the first volcanic activity in the middle Miocene.

Structures found in the Columbia River Basalt Group are subdivided by Newcomb (1969) into five major types: (1) Basin and Range type block faulting, fading northwest into longer, open ended structures; (2) the Blue Mountain anticline, which is the largest single uplift in the region; (3) long, north-south running tilted fault blocks along the west side of the Idaho batholith; (4) structures which branch directly from the Cascade Range, examplified by the Yakima Ridges and (5) the band of horizontal basalt extending along the west side of the northern Rocky Mountains from Mount Idaho to the Okanogan Highlands.

Basic geochemical variations between flows, members and formations are found throughout the succession of the Columbia River Group. At the base of the stratigraphic column, the Picture Gorge Formation shows a relatively high concentration of MgO and has intermediate SiO_2 relative to MgO. The overlying Grande Ronde Basalt, however, tends to be lower in MgO and higher in SiO_2. The Wanapum Basalt, next in stratigraphic sequence, has about the same proportion of MgO as Grande Ronde, but is lower in SiO_2 and higher in FeO and TiO_2 relative to MgO. The Saddle Mountains Basalt, youngest in the Columbia

River sequence, has a high geochemical variation between flows, with the two lowest flows having the lowest SiO_2 and highest FeO, TiO_2 and highest P_2O_5 reative to MgO of any flows found in the Cloumbia River Basalt sequence (Hooper (1982)).

The samples used in the research for this paper are a set of fifteen rock samples collected from an unidentified outcrop in the Columbia River Basalt Group. Also included was a cross section (Fig. 3) and stratigraphic location for each rock sample. The purpose of this paper is to identify the flows in terms of modern stratigraphic nomenclature and to locate the section geographically. Furthermore, the samples will be described petrographically to confirm that the petrography of the samples corrolates with that for rocks from the inferred geographic location.

Bingham and Grolier (1966, fig. 1)		Informal nomenclature of Wright and others (1973, table 1)		Swanson and others (1978, Table 1)	
Yakima Basalt	Saddle Mountains Member	Yakima basalt	Upper Yakima basalt:	Yakima Basalt Subgroup	Saddle Mountains Basalt:
			Flows at Ice Harbor Dam		Lower Monumental Member (new)
					Ice Harbor Member (new)
					Buford Member (new)
			Ward Gap and Elephant Mountain basalt of Schmincke (1967a)		Elephant Mountain Member
			Pomona basalt of Schmincke (1967a)		Pomona Member
					Esquatzel Member (new)
					Weissenfels Ridge Member (new)
					Asotin Member (new)
					Wilbur Creek Member (new)
					Umatilla Member
			Middle Yakima basalt:		Wanapum Basalt (new):
	Priest Rapids Member		Priest Rapids member, including Umatilla basalt of Schmincke (1967a); Lolo Creek flow of Bond (1963)		Priest Rapids Member
	Quincy Diatomite Bed				
	Roza Member		Roza Member		Roza Member
	Squaw Creek Diatomite Bed				
	Frenchman Springs Member		Frenchman Springs Member		Frenchman Springs Member
					Eckler Mountain Member (new)
	Vantage Sandstone Member				
	Lower basalt flows		Lower Yakima basalt		Grande Ronde Basalt (new)
			Picture Gorge basalt		Picture Gorge Basalt
			Lower basalt of Bond (1963)		Imnaha Basalt

FIG 2

After Swanson and others (1979

STRATIGRAPHY

The cross section shown in Fig. 3 displays the stratigraphic sequence in the area of sample collection. This is almost identical to Fig. 2 in Mackin's 1961 publication, which is a cross section of the area where his study took place. Mackin groups all of the members shown on his cross section into the Yakima Basalt Formation.

Changes made in stratigraphic nomenclature between 1961 and 1979 necessitate an explanation of where changes have taken place and where units shown in Fig. 3 fit into the present day stratigraphy put forth by Swanson and others (1979) - Fig. 1.

The Priest Rapids, Roza and Frenchman Springs Members were all named by Mackin (1961). He divided the Priest Rapids Member into four flows designated by numbers and the Frenchman Springs Member into the Ginkgo, Sand Hollow and Sentinel Gap flows. Bingham and Grolier (1966) referred to the Priest Rapids Member as the Quincy Diatomite Bed, which is the lateral equivalent of one or more of the Priest Rapids flows. A second diatomite bed, referred to as the Squaw Creek Diatomite Bed is also mentioned. This bed is the lateral equivalent of the Sentinel Gap flow of the Frenchman Springs Member.

The sequence of Frenchman Springs, Roza and Priest Rapids has been kept by Swanson and others (1979) - Fig. 2. Underlying the Frenchman Springs Member is a new unit defined by Swanson and others (1979) as the Eckler Mountain Member. The Eckler Mountain through Priest Rapids Member were, in this 1979 publication, redefined as part of the Wanapum Basalt Formation, and the previous formation name of Yakima Basalt was raised to subgroup status. Swanson and others (1979) also defined another formation, the Grande Ronde Basalt, as underlying the Wanapum Basalt (Fig. 2).

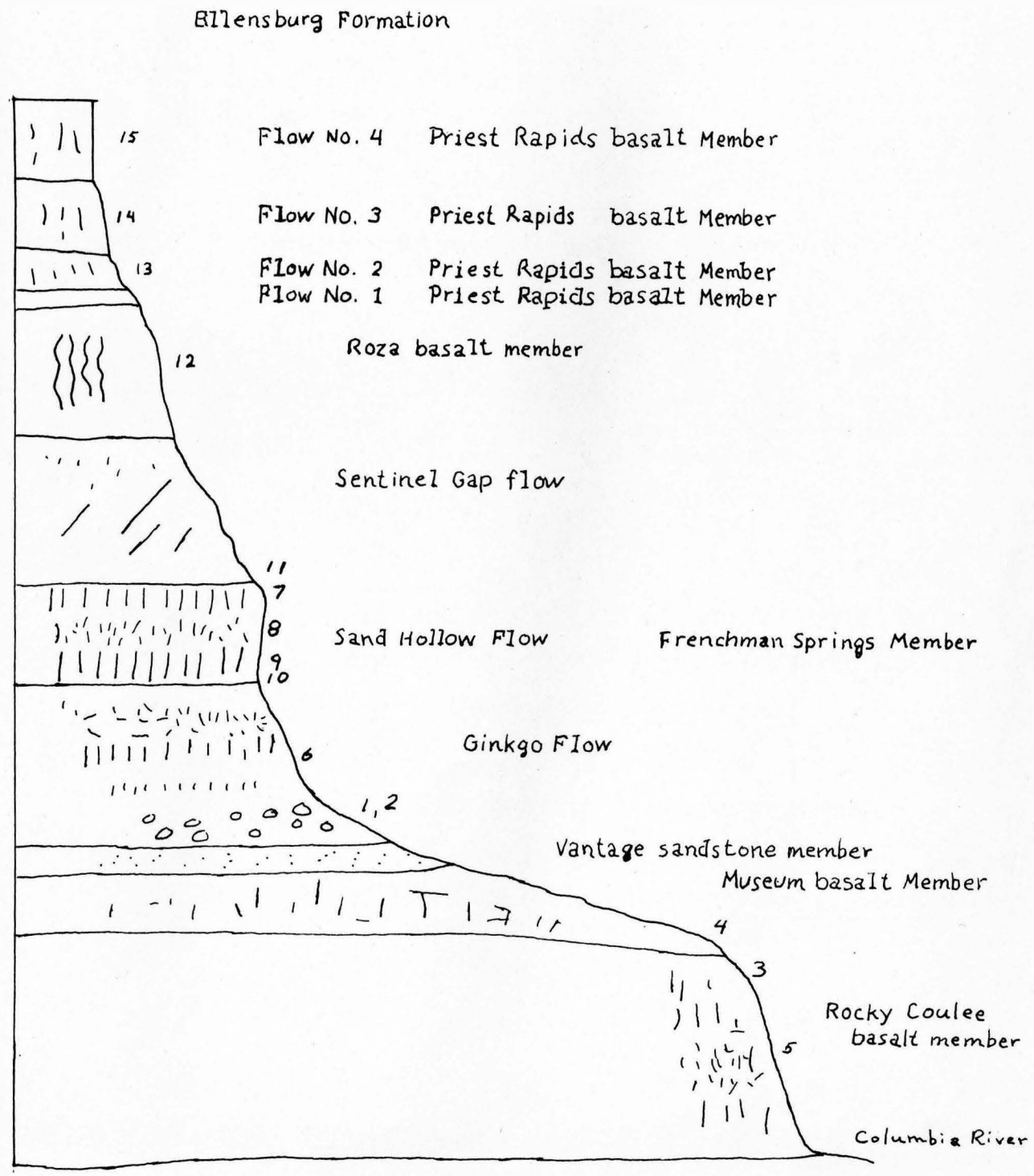

FIG 3 Cross Section of area of sample collection

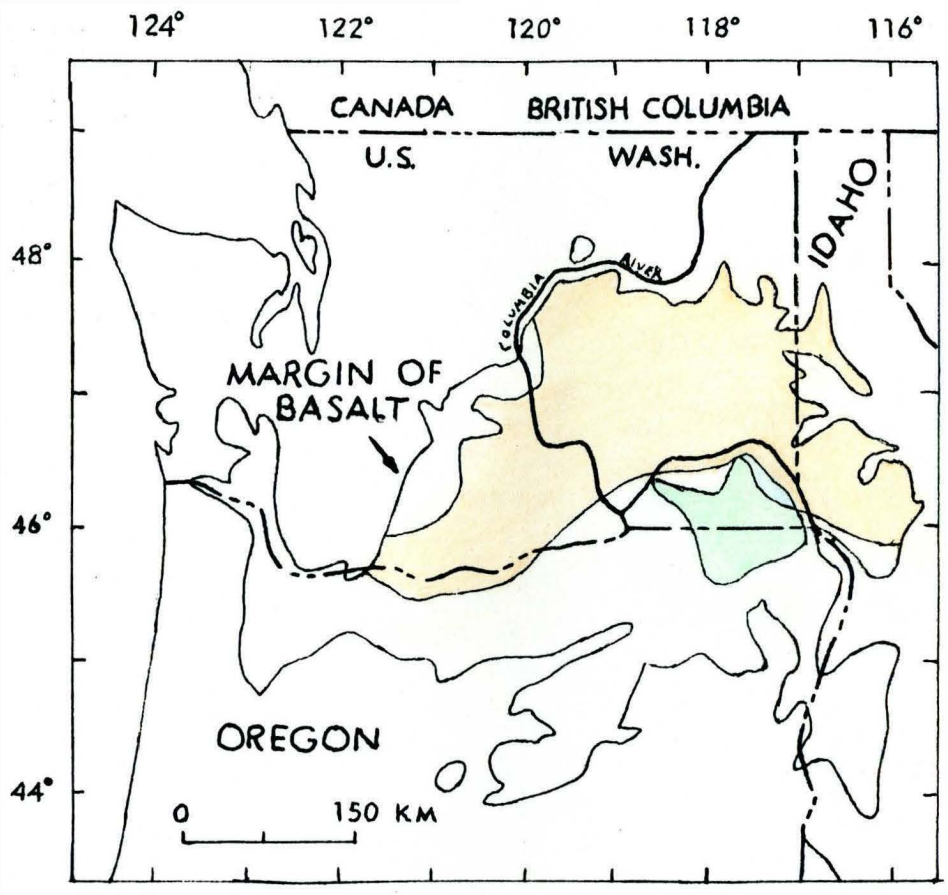

FIG. 4

Inferred distribution of Priest Rapids Member

Inferred distribution of Eckler Mountain Member

Area of probable Priest Rapids - Eckler Mountain Overlap

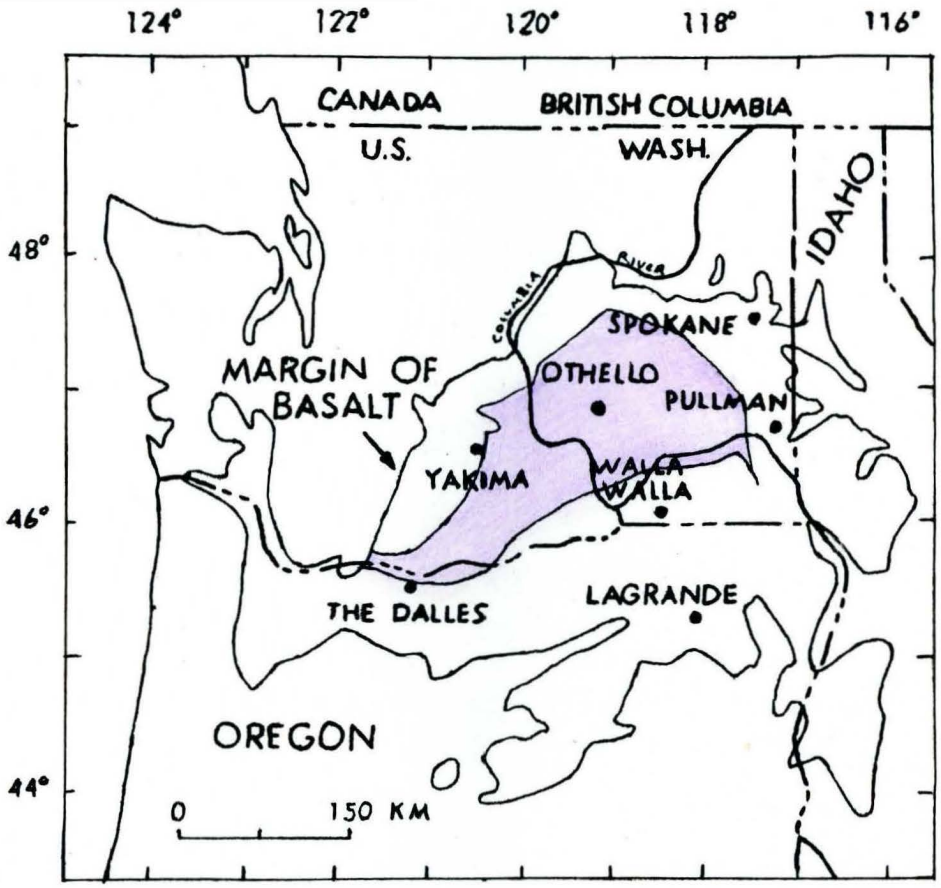

FIG 5

Area of possible stratigraphic overlap of Grande Ronde Basalt, Frenchman Springs Member, Roza Member and Priest Rapids Member

After Swanson and Others (1979)

Underlying the Frenchman Springs Member in Fig.3 is the Vantage Sandstone Mrmber. Since west of the type locality, the Vantage Sandstone merges laterally with and cannot be separated from the Ellensburg Formation, Swanson and others (1979) redefined the Vantage Sandstone Member as part of the Ellensburg Formation.

The question now arises as to where the Rocky Coulee and Museum Members fit into the recent stratigraphic nomenclature. Since no available literature more recent than Mackin's 1961 publication correlates directly with these flows, other data must be used to determine where they fit in the stratigraphic sequence.

Any member of formation to which the Rocky Coulee and Museum Members now belong must fill two criteria: (1) It must be separated by the Ellensburg sedimentary interbed from the Frenceman Springs, Roza and Priest Rapids Basalt Members in a particular locality and (2) this locality must occur along the banks of the Columbia River, since the area of sample collection lay there (Fig.3).

The most logical first step is to assume that these members might have been redefined as part of the Eckler Mountain Member of the Wanapum Basalt, Figure 4 shows the geographic extent of the Priest Rapids and Eckler Mountain Members in the Columbia River Basalt area. The intersection of the two shows the area of possible overlap of the Priest Rapids and Eckler Mountain Members Clearly, this area fails to meet one of the criteria, nowhere is it exposed along the banks of the Columbia River.

The next step is to assume that the Rocky Coulee and Museum Members might be part of the Grande Ronde Basalt. Figure 5 represents the area of possible

overlap of Grande Ronde, Frenchman Springs, Roza and Priest Rapids. This area fills both of the two required criteria, it gives an area in which the sequence of units is found, and it can be exposed for a long distance along the Columbia River's banks.

Swanson and others (1979) also state that the Grande Ronde "is generally well defined by a zone of weathering and(or) a sedimentary interbed separating the formation from the overlying Wanapum and Saddle Mountains Basalt." This sedimentary interbed can easily be interpreted as the short section of Ellensburg Formation separating the Museum and Frenchman Springs Members. By this and the above information, the Rocky Coulee and Museum Members are inferred to be part of the Grande Ronde Basalt Formation.

Fig. 6 displays a cross section showing the stratigraphic succession in nomenclature used by Mackin (1961) with that used by Swanson and others (1979).

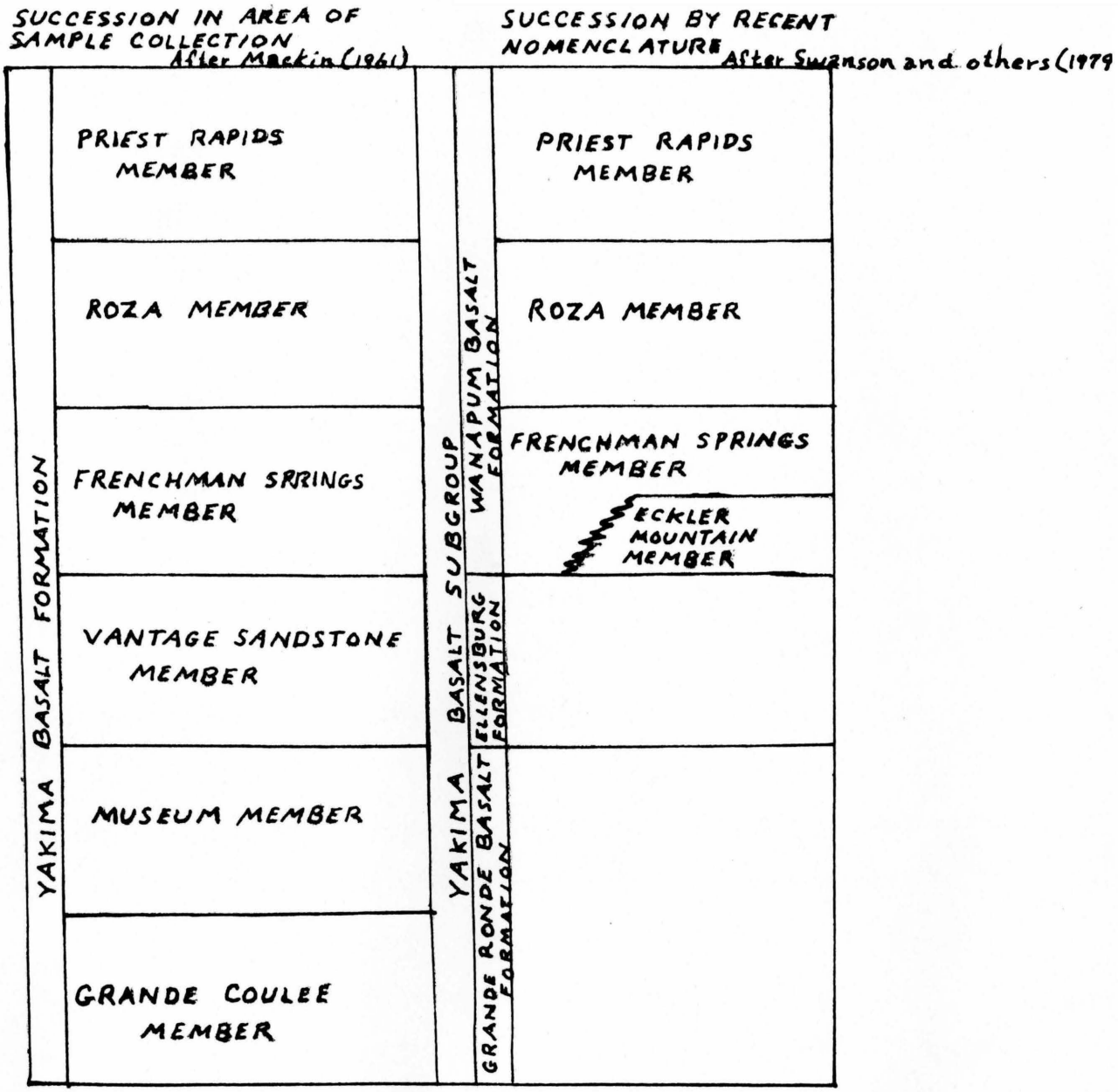
SUCCESSION IN AREA OF SAMPLE COLLECTION
After Mackin (1961)
SUCCESSION BY RECENT NOMENCLATURE
After Swanson and others (1979
YAKIMA BASALT FORMATION
PRIEST RAPIDS MEMBER
ROZA MEMBER
FRENCHMAN SRRINGS MEMBER
VANTAGE SANDSTONE MEMBER
MUSEUM MEMBER
GRANDE COULEE MEMBER
YAKIMA BASALT SUBGROUP
WANAPUM BASALT FORMATION
ELLENSBURG FORMATION
GRANDE RONDE BASALT FORMATION
PRIEST RAPIDS MEMBER
ROZA MEMBER
FRENCHMAN SPRINGS MEMBER
ECKLER MOUNTAIN MEMBER

FIG. 6

LOCATION

With the stratigraphy of the area of sample collection now determined, this information may be used to infer the geographic location of this area. The two criteria given earlier for stratigraphic correlation must also be met when dealing with the geographic locality, ie; the area must have the stratigraphic sequence given in Fig. 6 and must occur along the banks of the Columbia River.

As mentioned earlier, Fig. 2 of Mackin's 1961 publication corresponds directly with the cross section of the area of sample collection found in Fig. 3. The locality of the cross section given in Macklin lies along the Columbia River in the Vantage-Priest Rapids area of south-central Washington. This sequence may now be traced north and south along the Columbia River to cover the total amount of area in which it may occur.

The Rocky Coulee and Museum Members were never given geographic distributions in the available literature. Subsequent to 1961, these members are generally referred to as the lower basalt flows of the Yakima Formation, or as part of the Grande Ronde Basalt Formation. The Grande Ronde Basalt is distributed over an enormous area covering all but the southern outlying margin of the Columbia River Group. Due to it's low stratigraphic position and generally poor outcropping other than in deep canyons, it is of little use in geographic determinations.

The Frenchman Springs Member consists of three flows in the area of sample collection. The Ginkgo flow is known to outcrop as far west as it's type locality in the lower part of Schnebly Coulee west of Vantage. The Sand Hollow flows type locality is found in cliff exposures north and south of the tributary mouth of Sand Hollow Creek, just east of Vantage. The Sentinel

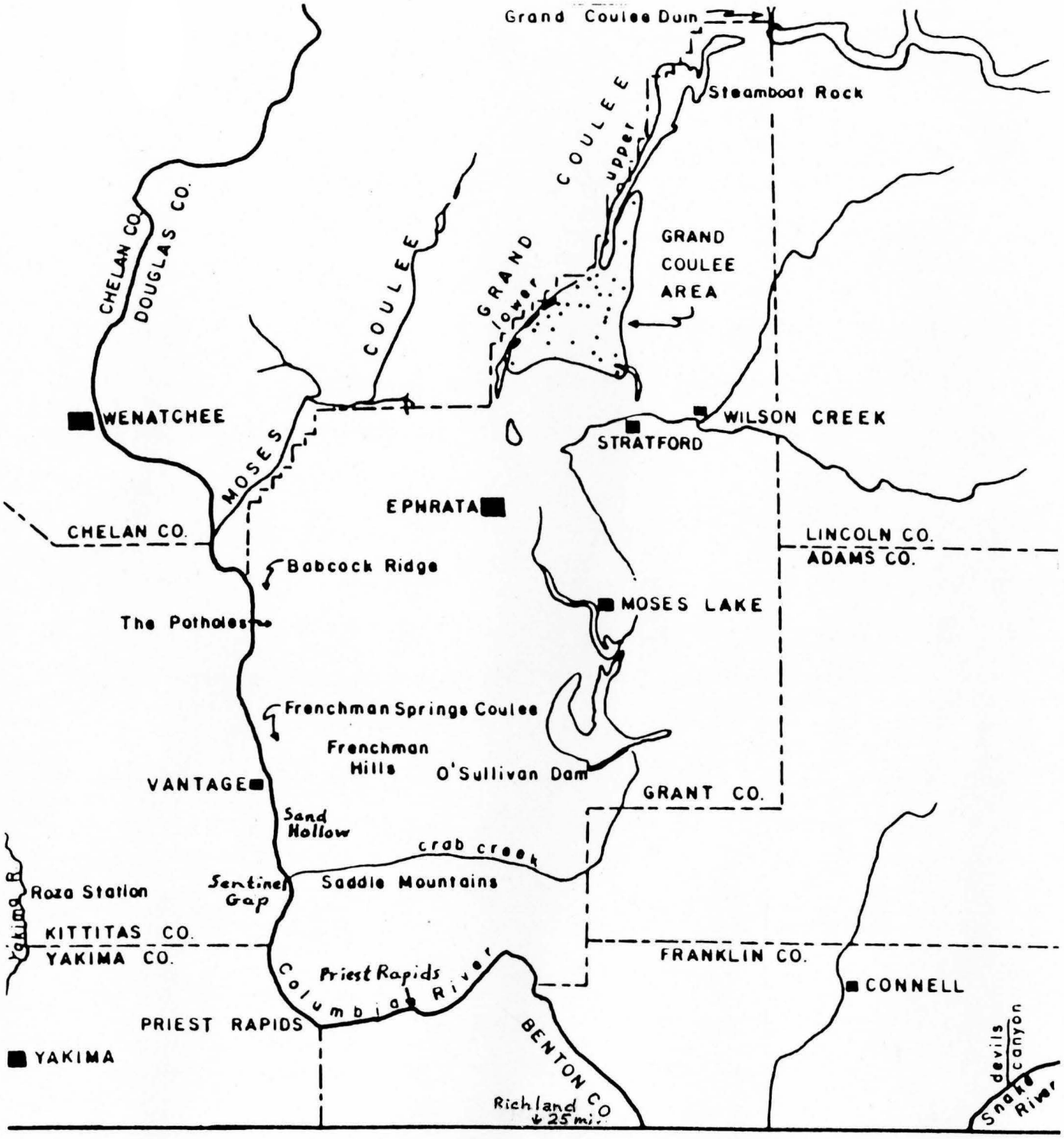

FIG 7

After Lefebure (1970)

INDEX MAP
CENTRAL WASHINGTON

N

5 0 5 10 15 20 Miles
SCALE

Gap flow provides a northern boundry for the sequence where it thins out two miles north of Sand Hollow. It's type locality is found just south of the mouth of Sand Hollow Creek.

The Roza Member in the Vantage-Priest Rapids area consists of a single flow reported by Bingham and Grolier (1966) to cover an area of some 200,000 square miles. This flow has been identified as far north as Coulee City, south to Pendleton, Oregon, east to Colfax and west to Goldendale. While this bed provides a key stratigraphic marker throughout much of the Columbia River Basalt, it does little to aid in the determination of geographic locality of sample collection.

Lefebvre (1970) reports several flows of the Roza Member found in and around central Washington which periodically die out, changing number from place to place. Due to it's great geographical extent, one of these flows can be assumed to be the key marker bed. In terms of number of flows, one to three flows along Wilson Creek, three to four flows near Stratford, two flows near O'Sullivan Dam, two flows near Connell and two flows in Devil's Canyon.

The two flows found at O'Sullivan, Connell and Devil's Canyon indicate that the sequence of basalt flows found in the Vantage-Priest Rapids area does not extend farther east that these areas. By the orientation of these locations (Fig. 7), it is quite possible that these are the same two flows at each location. If one flow is the key marker bed, the other flow would have died out somewhere between these areas and the Vantage-Priest Rapids vicinity.

Fig. 5 displays the largest possible area in which the sequence shown in Fig. 3 can occur along the Columbia River. This area extends to just north of where the Sentinel Gap flow dies out. Since the southern geographical

extents of the individual flows are not recorded, only the maximum southerly extent of the sequence can be given. This is shown in Fig. 5 to be somewhere near Richland along the Columbia River.

PETROGRAPHY

The petrography of the basalts studied contain many characteristics common throughout the succession of the Columbia River Basalts. All basaltic specimens examined contain varying amounts of plagioclase, augite, olivine and opaques. Twelve of the fourteen basalt specimens also contain pigeonite. Two interstitial materials, one a quartzofeldspathic intergrowth and the other the mineraloid chlorophaeite, are also present in varying amounts in every sample observed. The mineralogy is typical of tholeiitic basalts.

Most samples were found to have a sparsely porphyritic texture. Two subporphyritic specimens were found and also one aphanitic rock sample was observed.

Plagioclase ranges from labradorite (An_{56}) in the Rocky Coulee and Roza Members to andesine (An_{43}) in the upper part of the Sand Hollow flow. Labradorite is slightly more common than andesine in the samples and is found in 8 of the 14 basalt specimens examined. The largest phenocrysts of plagioclase found per sample range from 1.0 mm. in the Sand Hollow flow, Sentinel Gap flow and Rocky Coulee Member to 1.5 mm. in the upper Priest Rapids Member. The dominent albite-Carlsbad twinning with scattered pericline twinning is found in all basalt samples. All crystals of the plagioclase are unaltered. Zoning is generally found on the margins of the plagioclase laths.

Two pyroxenes, augite and pigeonite, are present. Pigeonite is found in all but the lower Sand Hollow flow and upper Priest Rapids Member. No alteration is found in any of the pyroxene grains. Pyroxene crystals are frequently subophitic with plagioclase laths. Maximum grain sizes of pyroxenes per sample range from 0.7 mm. in the lower Rocky Coulee Member to 0.3 mm. in

the upper Rocky Coulee and upper Sand Hollow Members.

Olivine is found in every sample collected. Crystals of olivine are generally subhedral to anhedral, however, euhedral varieties are found in the upper Priest Rapids Member. 2V ranges 80-90 degrees. Approximate composition is Fo_{65} - Fo_{88}. Although most of the olivine is unaltered, alteration to the mineraloid iddingsite is found in grain fractures in samples from the Rocky Coulee and upper Priest Rapids Members. The largest grain sizes per sample range from 0.3 mm. in the Rocky Coulee Member, Ginkgo flow and Sand Hollow flow to 0.8 mm. in the Priest Rapids Member.

Interstitial materials are found in two varieties in all basalt samples examined.

The first variety of interstitial material is a quartzofeldspathic intergrowth which is brown to reddish-brown in color. Partial extinction due to included oxides is generally seen between crossed nicols. All examples contain small crystals of apatite and small, blocky opaques as inclusions.

The second variety of interstitial material is the mineraloid chlorophaeite which is yellow to yellow-brown in color. Variations in color include red, reddish-brown and colorless. When viewed between crossed nicols, it is isotropic, dark green or red.

Opaques are displayed in three forms. One is blocky with edge angles near 90 degrees and is interpreted as magnetite. Ilmenite occasionally appears as subhedral hexagons. The third form is in acicular grains and is

interpreted as magnetite and/or ilmenite.

The exception to the tholeiitic basalt lavas is sample #1. This is a breccia which probably represents extrusion of the Ginkgo flow into a lake. (Figure 3)

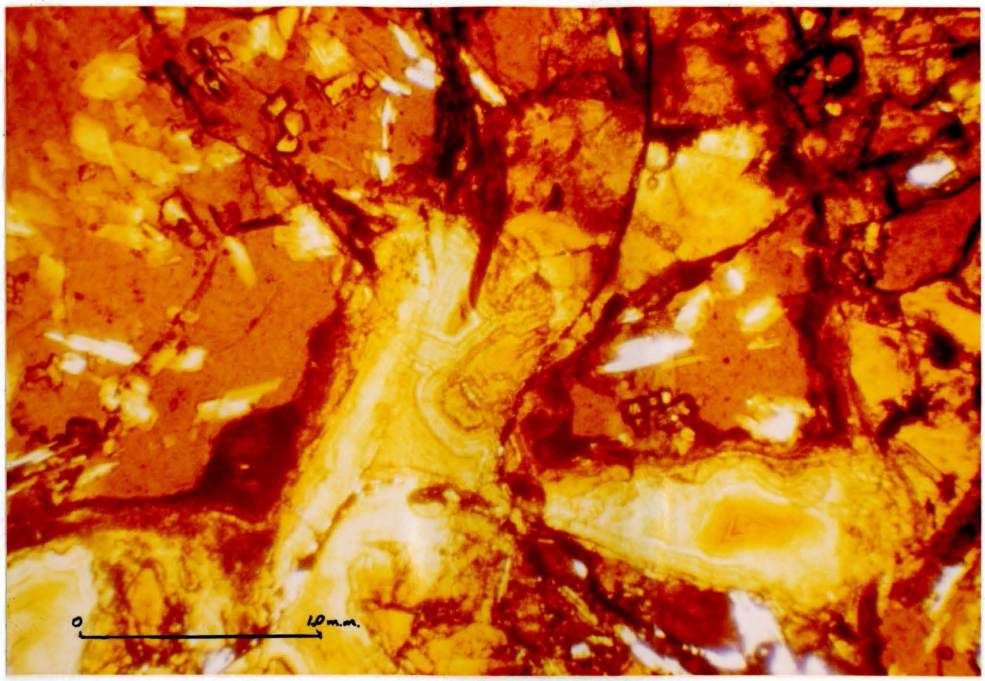

Figure 8: Chlorophaeite alteration in breccia

Figure 9: Aphanitic texture in the Priest Rapids Member

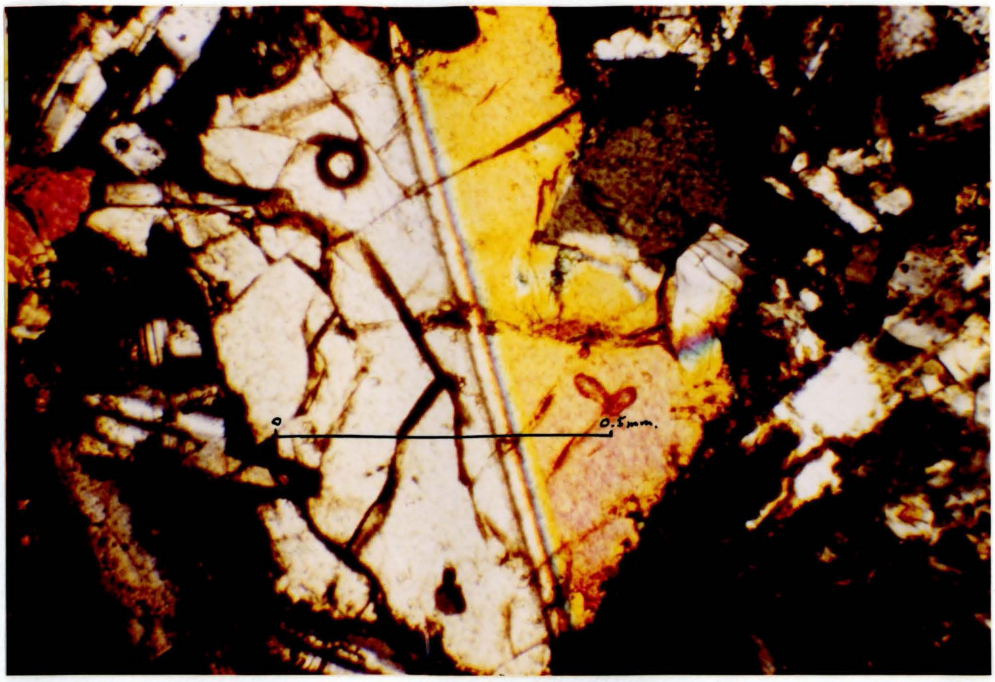

Figure 10: Twinning in augite

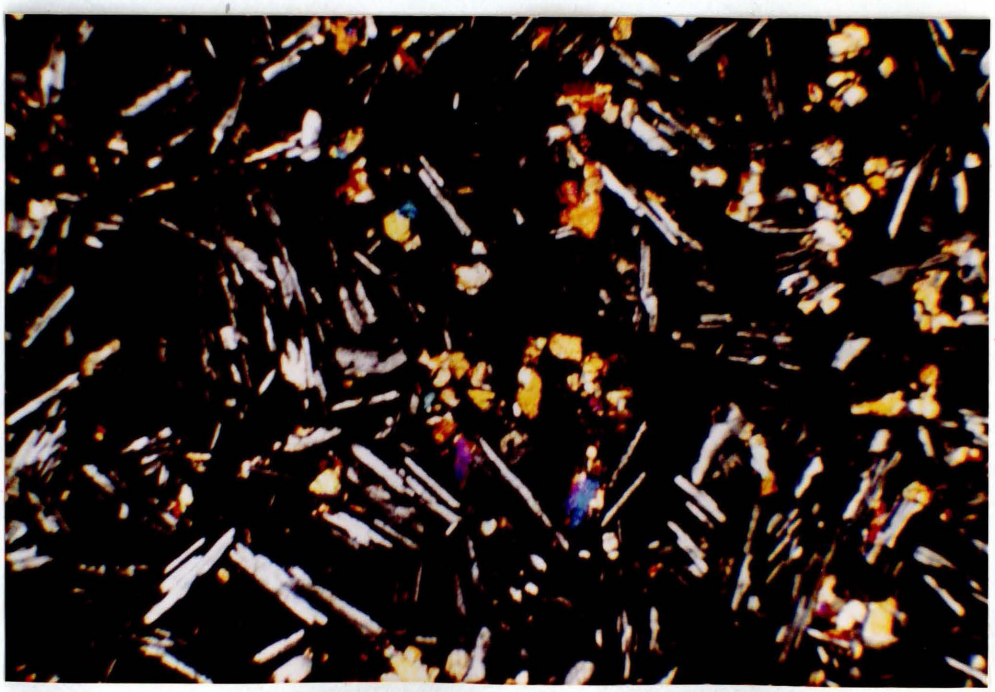

Figure 11: Quartzofeldspathic intergrowths (Crossed nicols)

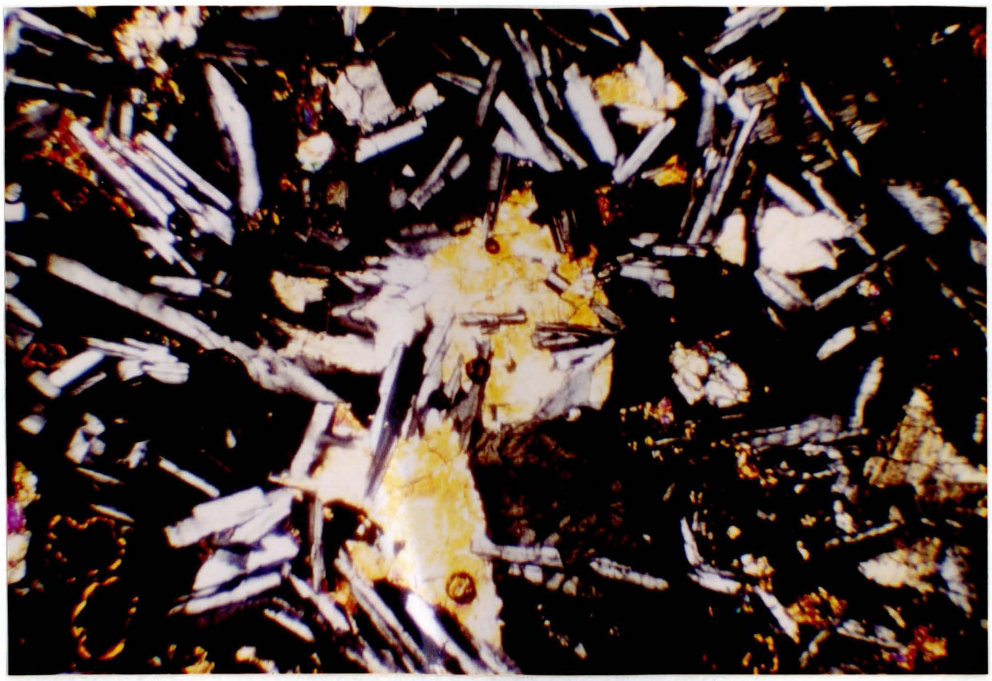

Figure 12: Augite subophitic with plagioclase

SUMMARY

The analysis of the samples and cross section given have revealed several characteristics of this paricular sequence.

(1) The sequence can be identified in terms of modern nomenclature. The Rocky Coulee and Museum Members are now considered part of the Grande Ronde Basalt Formation. All units that overlie the Vantage Sandstone and underlie the main body of the Ellensburg Formation (i.e. the Frenchman Springs, Roza and Priest Rapids Members) have kept their names and status as members, but are now grouped into the Wanapum Basalt Formation. The previous formation name of Yakima Basalt was raised to subgroup status and now includes the Grande Ronde, Wanapum and Saddle Mountains Formations.

(2) The geographic location must have the sequence of strata given in Fig. 3 and also must occur somewhere along the banks of the Columbia River. This location can be determined to within certain geographical limits. These limits extend from the area two miles north of Sand Hollow in the north to Richland in the south (Fig. 7).

(3) The rocks in this sequence have petrography typical of tholeiitic basalts. This petrography is consistant with other published data.

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APPENDIX A

PETROGRAPHIC DESCRIPTIONS

Specimen #1

A brecciated rock composed of glass, plagioclase and olivine with interstitial mineraloid.

53% Glass- Glass is dark brown to colorless. It is isotropic. Index of refraction is less than plagioclase. Most fragments are highly fractured.

5% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is albite-Carlsbad type. Approximate composition is An_{57} - Labradorite. Crystals are unaltered. Zoning on the margins of laths. Grain sizes up to o.3 mm.

4% Olivine - Crystals are anhedral. Grains are colorless. 2 V approximately 85 - 90 degrees. Optic sign generally positive. Alteration to a mineraloid, probably iddingsite, found in the fractures of some grains. Grain sizes up to 0.6 mm.

37% One variety of interstitial material fills interstices between the glass fragments. This material is yellow in color. It's index of refraction is almost identical to the glass. This substance is interpreted as chlorophaeite.

1% Trace materials

Carbonate - Carbonate is found as a highly birefringent material filling voids between glass fragments.

Opaques - Several small, blocky opaques are found often included in the glass. Many grains have edge angles near 90 degrees. These are interpreted as magnetite.

Rock Name: Breccia

Specimen #2

A sparsely porphyritic rock containing phenocrysts up to 1.2 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzo-feldspathic minerals and a mineraloid.

35% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{54}-Labradorite. Crystals are unaltered. Zoning occurs on the margins of laths. Phenocrysts up to 1.2 mm.

17% Augite - Crystals are anhedral. Color is light brown to colorless. 2V approximately 50-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.5 mm.

2% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-15 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

6% Olivine - Crystals are anhedral. Grains are colorless with a sugary texture. 2V approximately 80-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.4 mm.

Interstitial Materials:

30% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly less than that of the surrounding plagioclase. Partial extinction is observed between

crossed nicols. Acicular grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

1% A second variety of interstitial material is yellow in color. It's index of refraction is slightly lower than that of the plagioclase. This material is isotropic. This substance is interpreted as the mineraloid chlorophaeite.

9% Opaques - Opaques appear in two forms, one being blocky with edge angles near 90 degrees, the other elongate and somewhat acicular. The blocky variety is interpreted as magnetite, while the acicular form is magnetite and/or ilmenite.

Rock Name: Tholeiitic Basalt

Specimen #3

A sparsely porphyritic rock containing phenocrysts up to 1.4 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzo-feldspathic minerals and a mineraloid.

40% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with some pericline twinning occasionally present. Approximate composition is An_{54}-Labradorite. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.4 mm.

13% Augite - Crystals are anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.3 mm.

5% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 10-20 degrees. Cleavage moderate to indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.3 mm.

5% Olivine - Crystals are anhedral. Grains are colorless with a sugary texture. 2V approximately 80-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.3 mm.

Interstitial Materials:

17% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than the surrounding plagioclase.

Partial extinction is observed between crossed polars. Acicular grains of a higher index mineral are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

1% A second variety of interstitial material is yellow to colorless. It's index of refraction is slightly than that of plagioclase. This material is isotropic. This substance is interpreted as the mineraloid chlorophaeite.

Opaques - Opaques appear as small, blocky grains with edge angles

9% near 90 degrees. These opaques are interpreted as magnetite.

Rock Name: Tholeiitic Basalt

Specimen #4

A sparsely porphyritic rock containing phenocrysts up to 1.2 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzo-feldspathic minerals and a mineraloid.

45% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{49}-Andesine. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.2 mm.

17% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.7 mm.

10% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-20 degrees. Grains are unaltered. Twinning is common. Cleavage is indistinct. Often subophytic with plagioclase. Grain sizes up to 0.7 mm.

2% Olivine - Crystals are anhedral. Grains are colorless with a sugary texture. 2V approximately 85-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.6 mm.

Interstitial Materials:

20% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than the surrounding plagioclase. Partial extinction is observed between crossed nicols. Accicular

grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

1% A second variety of interstitial material appears in small quantities dispersed throughout the thin section. Color of this material is dark yellow. It's index of refraction is slightly lower than that of the plagioclase. A dark green color is seen between crossed nicols, but this is not interpreted as birefringence. This material is interpreted as the mineraloid chlorophaeite.

5% Opaques - Opaques appear in two forms, the most common being elongate and somewhat acicular. The other form is blocky with edge angles near 90 degrees. The blocky opaques are interpreted as magnetite and the acicular grains as magnetite and/or ilmenite. Grain sizes up to 0.5 mm.

Rock Name: Tholeiitic Basalt

Specimen #5

A sparsely porphyritic rock containing phenocrysts up to 1.5 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzo-feldspathic materials and a mineraloid.

38% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{-56}-Labradorite. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.5 mm.

15% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.6 mm.

6% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-20 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

3% Olivine - Crystals are subhedral to anhedral. Grains are colorless with a sugary texture. 2V approximately 85-90 degrees. Optic sign generally negative, some optically positive grains found. Alteration to a mineraloid, probably iddingsite, is found in the fractures of some grains. Grain sizes up to 0.4 mm.

Interstitial Materials:

30% One variety of interstitial material is reddish-brown in color. It's

index of refraction is slightly lower than the surrounding plagioclase. Partial extinction is observed between crossed nicols. Acicular grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

5% A second variety of interstitial material is yellow in color. It's index of refraction is slightly lower than that of the plagioclase. This material is isotropic. This substance is interpreted as the mineraloid chlorophaeite.

4% Opaques - Opaques are small and blocky with edge angles near 90 degrees. These opaques are interpreted as magnetite. Grain sizes up to 0.1 mm.

Rock Name: Tholeiitic Basalt

Specimen #6

A sparsely porphyritic rock containing phenocrysts up to 1.3 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzofeldspathic minerals and a mineraloid.

44% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with perecline twinning occasionally present. Approximate composition is An_{50}-Labradorite. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.3 mm.

6% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 55-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.6 mm.

9% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-15 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

10% Olivine - Crystals are subhedral to anhedral. Grains are colorless with a sugary texture. 2V approximately 85-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.3 mm.

Interstitial Materials:

17% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than the surrounding plagioclase. Partial extinction is observed between crossed nicols. Âcicular

grains of a higher index mineral and small, blocky opaques are included. This interstitial substance is interpreted as a quartzo-feldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

6% A second variety of interstitial material is dark yellow-brown in color. It's index of refraction is slightly lower than that of plagioclase. A dark green color is seen between crossed nicols, but is not interpreted as birefringence. This material is interpreted as the mineraloid chlorophaeite.

8% Opaques - Opaques are blocky and angular in form, with edge angles near 90 degrees. These opaques are interpreted as magnetite. Grain sizes up to 0.4 mm.

Rock Name: Tholeiitic Basalt

Specimen #7

A very sparsely porphyritic rock containing phenocrysts up to 1.3 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzo-feldspathic minerals and a mineraloid.

45% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{43}-Andesine. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.3 mm.

10% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

13% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-20 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.3 mm.

7% Olivine - Crystals are anhedral. Grains are colorless with a sugary texture. 2V approximately 80-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.6 mm.

Interstitial Materials:

8% One variety of interstitial material is light brown to reddish-brown in color. It's index of refraction is slightly lower than that of the plagioclase. Partial extinction is observed between crossed nicols.

Acicular grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the mineral it's color. The higher index acicular crystals are probably apatite.

7% A second variety of interstitial material is dark yellow in color. It's index of refraction is slightly lower than that of the plagioclase. This material is isotrophic. This substance is interpreted as the mineraloid chlorophaeite.

10% Opaques - Opaques appear in two forms, one being blocky with edge angles near 90 degrees, the other forms subhedral hexagons. The blocky opaques are interpreted as magnetite while the hexagonal grains are ilmenite. Grain sizes up to 0.3 mm.

Rock Name: Tholeiitic Basalt

Specimen #8

A sparsely porphyritic rock containing phenocrysts up to 1.0 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzo-feldspathic minerals and an mineraloid.

43% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{47}-Andesine. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.0 mm.

9% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 45-60 degrees. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

13% Pigeonite - Crystals are subhedral to euhedral. Color is light brown to colorless. 2V approximately 0-20 degrees. Cleavage moderate to indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

10% Olivine - Crystals are anhedral. Grains are colorless with a sugary texture. 2V approximately 80-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.3 mm.

Interstitial Materials:

10% One variety of interstitial material is light brown to colorless. It's index of refraction is slightly lower than the surrounding plagioclase. Partial extinction is observed between crossed nicols.

Acicular grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the light brown color. The higher index acicular crystals are probably apatite.

8% A second variety of interstitial material is yellow-brown in color. It's index of refraction is slightly lower than the plagioclase. A dark green color is seen between crossed nicols, but is not interpreted as birefringence. This material is interpreted as the mineraloid chlorophaeite.

7% Opaques - Opaques appear in two forms, one being elongate and somewhat acicular, the other blocky with edge angles near 90 degrees. The blocky grains are interpreted as magnetite while the acicular grains are magnetite and/or ilmenite. Grain sizes up to 0.5 mm.

Rock Name: Tholeiitic Basalt

Specimen #9

A sparsely porphyritic rock containing phenocrysts up to 1.0 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzo-feldspathic minerals and a mineraloid.

45% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{35}-Andesine. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.0 mm.

15% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.7 mm.

7% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-15 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.5 mm.

5% Olivine - Crystals are subhedral to anhedral. Grains are colorless with a sugary texture. 2V approximately 85-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.6 mm.

Interstitial Materials:

15% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than the plagioclase. Partial extinction is observed between crossed nicols. Acicular

crystals of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

5% A second variety of interstitial material is yellow-brown in color. It's index of refraction is slightly lower than the plagioclase. A dark green color which is not interpreted as birefringence is seen between crossed nicols. This substance is interpreted as the mineraloid chlorolpaeite.

8% Opaques - Opaques appear in two forms, one is blocky with edge angles near 90 degrees, the other forms subhedral hexagons. The blocky form is interpreted as magnetite and the hexagonal form as ilmenite. Grain sizes up to 0.5 mm.

Rock Name: Tholeiitic Basalt

Specimen #10

A sub-porphyritic rock containing phenocrysts up to 1.2 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzofeldspathic minerals and a mineraloid.

30% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning generally is albite-Carlsbad, with pericline twinning occasionally present. Approximate composition is An_{48}-Andesine. Crystals are unaltered. Zoning found in the margins of laths. Phenocrysts up to 1.2 mm.

30% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Cleavage is moderate to indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 1.0 mm.

3% Olivine - Crystals are anhedral. Grains are colorless with a sugary texture. 2V approximately 85-90 degrees. Optic sign generally negative. Crystals are unaltered. Grain sizes up to 0.5 mm.

Interstitial Materials:

20% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than the surrounding plagioclase. Partial extinction is observed between crossed nicols. Acicular crystals of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apitite.

7% A second variety of interstital material is yellow-brown in color. It's index of refraction is slightly lower than that of the plagioclase. The yellow-brown color is maintained under crossed nicols. This is interpreted as the mineraloid chlorophaeite.

10% Opaques - Opaques come in two forms, one being blocky with edge angles near 90 degrees and the other elongate and somewhat acicular. The blocky form is interpreted as magnetite while the acicular grains are magnetite and/or ilmenite.

Rock Name: Tholeiitic Basalt

Specimen #11

A sparsely porphyritic rock containing widely scattered phenocrysts up to 1.0 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzofeldspathic minerals and a mineraloid.

38% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{50}-Andesine-Labradorite. Crystals are unaltered. Zoning found on the margins of laths.

14% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.5 mm.

4% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-15 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.5 mm.

8% Olivine - Crystals are anhedral to euhedral. Grains are colorless with a sugary texture. 2V approximately 85-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.4 mm.

Interstitial Materials:

20% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than the surrounding plagioclase. Partial extinction is observed between crossed nicols. Acicular

grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

7% A second variety of interstitial material is yellow-brown in color. It's index of refraction is slightly lower than that of the plagioclase. This material is isotropic. This substance is interpreted as the mineraloid chlorophaeite.

9% Opaques - Opaques appear in two forms, one being blocky with edge angles near 90 degrees, the other is elongate and somewhat acicular in form. The blocky variety is interpreted as magnetite while the acicular grains are magnetite and/or ilmenite.

Rock Name: Tholeiitic Basalt

Specimen #12

A sparsely porphyritic rock containing phenocrysts up to 1.2 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzo-feldspathic minerals and a mineraloid.

35% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{56}-Labradorite. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.2 mm.

13% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 50-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.5 mm.

7% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-15 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

5% Olivine - Crystals are anhedral. Grains are colorless with a sugary texture. 2V approximately 80-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.4 mm.

Interstitial Materials:

20% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than the surrounding plagioclase. Partial extinction is observed between crossed nicols. Acicular

grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

10% A second variety of interstitial material is yellow-brown in color. It's index of refraction is slightly less than that of the plagioclase. A dark green color, not interpreted as birefringence, is seen between crossed nicols. This substance is interpreted as the mineraloid chlorophaeite.

10% Opaques - Opaques come in three forms, one being elongate and somewhat acicular, another blocky with edge angles near 90 degrees and the third forming subhedral hexagons. The blocky form is interpreted as magnetite, the hexagonal as ilmenite and the acicular variety as magnetite and/or ilmenite.

Rock Name: Tholeiitic Basalt

Specimen #13

An aphanitic rock composed of plagioclase laths, pyroxene, olivine and opaques with interstitial quartzofeldspathic minerals and a mineraloid.

40% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with some pericline twinning occasionally present. Approximate composition is An_{51}-Labradorite. Crystals are unaltered. Zoning found in the margins of laths. Grain sizes up to 0.5 mm.

14% Augite - Crystals are anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Grains are unaltered. Twinning is common. Cleavage is indistinct. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

6% Pigeonite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 0-20 degrees. Grains are unaltered. Twinning is common. Cleavage is indistinct. Often subophitic with plagioclase. Grain sizes up to 0.4 mm.

2% Olivine - Crystals are subhedral to anhedral. Grains are colorless with a sugary texture. 2V approximately 80-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.4 mm.

Interstitial Materials:

25% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than that of the plagioclase. Partial extinction is observed between crossed nicols. Acicular of a higher index mineral and small, blocky opaques are included

in it. This interstitial substance is interpreted as a quartzo-feldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

7% A second variety of interstitial material is light yellow in color. This material is isotropic. It's index of refraction is slightly lower than that of plagioclase. This material is interpreted as the mineraloid chlorophaeite.

6% Opaques - Opaques appear in two forms, one is elongate and somewhat acicular, the other blocky with edge angles near 90 degrees. These blocky opaques are interpreted as magnetite with the acicular grains being magnetite or ilmenite. Grain sizes up to 0.6 mm.

Rock Name: Tholeiitic Basalt

Specimen #14

A sparsely porphyritic rock containing widely scattered phenocrysts up to 1.0 mm. set in plagioclase laths, pyroxene, and olivine with interstitial quartzofeldspathic minerals and a mineraloid.

40% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad, with some pericline twinning occasionally present. Approximate composition is An_{54}-Labradorite. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.0 mm.

15% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. 2V approximately 40-60 degrees. Cleavage is indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.6 mm.

3% Pigeonite - Crystals are subhedral to euhedral. Color is light brown to colorless. 2V approximately 0-20 degrees. Cleavage moderate to indistinct. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 0.5 mm.

6% Olivine - Crystals are anhedral. Grains are colorless with a sugary texture. 2V approximately 85-90 degrees. Optic sign generally negative. Grains are unaltered. Grain sizes up to 0.8 mm.

Interstitial Materials:

22% One variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than the surrounding plagioclase. Partial extinction is observed between crossed nicols. Acicular

grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a quartzofeldspathic intergrowth with birefringence masked by oxides which give the reddish-brown color. The higher index acicular crystals are probably apatite.

6% A second variety of interstitial material is yellow to dark red in color. It's index of refraction is slightly lower than that of plagioclase. The red color is maintained between crossed nicols. This material is interpreted as the mineraloid chlorophaeite.

8% Opaques - Opaques appear in two forms, one is long and somewhat acicular, the other blocky with edge angles near 90 degrees. The blocky opaques are interpreted as magnetite with the acicular grains being manetite and/or ilmenite. Grain sizes up to 1.1 mm.

Rock Name: Tholeiitic Basalt

Specimen #15

A sub-porphyritic rock containing phenocrysts up to 1.2 mm. set in plagioclase laths, pyroxene, olivine and opaques with interstitial quartzofeldspathic minerals and a mineraloid.

40% Plagioclase - Crystals are tabular to elongate, subhedral to euhedral. Twinning is generally albite-Carlsbad type, with pericline twinning occasionally present. Approximate composition is An_{45}-Andesine. Crystals are unaltered. Zoning found on the margins of laths. Phenocrysts up to 1.2 mm.

27% Augite - Crystals are subhedral to anhedral. Color is light brown to colorless. Cleavage is moderate to indistinct. 2V approximately 40-60 degrees. Grains are unaltered. Twinning is common. Often subophitic with plagioclase. Grain sizes up to 1.1 mm.

5% Olivine - Crystals anhedral to euhedral. Grains are colorless with a sugary texture. 2V approximately 80-90 degrees. Optic sign generally negative. Alteration to secondary mineraloid, probably iddingsite, is found in the fractures of some grains. Grain sizes up to 0.8 mm.

Interstitial Materials:

10% One variety of interstitial material is light brown to colorless. It's index of refraction is slightly lower than that of the plagioclase. First order whites and yellows are seen between crossed nicols. Acicular grains of a higher index mineral and small, blocky opaques are included in it. This interstitial substance is interpreted as a

a quartzofeldspathic intergrowth with oxides giving the light brown color. The higher index acicular grains are probably apatite.

7% A second variety of interstitial material is reddish-brown in color. It's index of refraction is slightly lower than that of the plagioclase. The reddish-brown color is maintained between crossed nicols. This substance is interpreted as the mineraloid chlorophaeite.

11% Opaques - Opaques appear in two forms, one is blocky with edge angles near 90 degrees, the other forms subhedral hexagons. The blocky opaques are interpreted as magnetite while the hexagonal grains are ilmenite.

Rock Name: Tholeiitic Basalt